Mon. Not. R. Astron. Soc. **000**, 1–?? (2005) Printed 5 February 2008 (MN LaTeX style file v2.2)

CCD photometry of distant open clusters NGC 2425, Haffner 10 and Czernik 29

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Accepted .... Received ....; in original form ....

ABSTRACT
We present BVI photometry for poorly known southern hemisphere open clusters: NGC 2425, Haffner 10 and Czernik 29. We have calculated the density profile and established the number of stars in each cluster. The colour-magnitude diagrams of the objects show a well-defined main sequence. However, the red giant clump is present only in NGC 2425 and Haffner 10. For these two clusters we estimated the age as 2.5 ± 0.5 Gyr assuming metallicity of $Z = 0.008$. The apparent distance moduli are in the ranges $13.2 < (m - M)_V < 13.6$ and $14.3 < (m - M)_V < 14.7$, while heliocentric distances are estimated to be $2.9 < d < 3.8$ kpc and $3.1 < d < 4.3$ kpc, respectively for NGC 2425 and Haffner 10. The angular separation of 2.4 deg (150 pc at mean distance) may indicate a common origin of the two clusters.

Key words: Hertzsprung-Russell (HR) diagram — open clusters and associations: individual: NGC 2425 — open clusters and associations: individual: Haffner 10 — open clusters and associations: individual: Czernik 29

1 INTRODUCTION

The most recent catalogue by Dias et al. (2002) presents data on 1537 Galactic open clusters. These are excellent objects with which to probe the structure and evolution of the Galactic disc. Since old and intermediate-age open clusters cover the entire lifetime of the disc, they allow us to trace the history of chemical enrichment and the formation of the different Galactic populations. For example, Salaris, Weiss & Percival (2004) determined the ages of 71 old open clusters and concluded that the thin and thick disc started to form at the same time. Carraro et al. (2004) observed open clusters from the outskirts of the disc and suggested that the outer part of the Galactic disc underwent a completely different evolution compared to the inner disc. Based on a sample of 39 open clusters, Friel et al. (2002) noted a slight correlation between metallicity and age for clusters in the outer disc beyond 10 kpc. Recently, intermediate-age open clusters were also found towards the Galactic Centre direction (Carraro, Méndez & Costa 2005), where star clusters do not survive for enough time due to the higher-density environment.

The observations of the clusters presented in this paper were conducted as a part of a photometric survey of a large sample of distant open clusters. The goal of the project was an identification of the oldest open clusters in order to obtain a lower limit on the age of the Galactic disc (Kaluzny & Rucinski 1995, see also references therein). In this paper, we present for CCD photometry of three faint open clusters: NGC 2425, Haffner 10 and Czernik 29. The equatorial and galactic coordinates of the cluster centres are listed in Table 1.

Table 1. Equatorial and galactic coordinates of target clusters

Name	RA(2000.0) [h:m:s]	Dec(2000.0) [° :′]	l [°]	b [°]
NGC 2425	07:38:22	-14:52.9	231.50	3.31
Haffner 10	07:28:36	-15:21.9	230.80	1.01
Czernik 29	07:28:23	-15:24.0	230.81	0.95

2 OBSERVATIONS AND REDUCTIONS

The observations were performed at the Las Campanas Observatory, using the 1.0-m Swope telescope equipped with a Tektronix 1024 × 1024 CCD camera. The field of view was about 11.′9 × 11.′9 with a scale 0.695 arcsec/pixel. The observations were conducted on two nights, Feb 20/21 and Feb 21/22, 1995. Two or three exposures of different length were taken in each of the BVI passbands. Preliminary processing of the CCD frames was done with standard routines in the IRAF package. Both, dome and sky flatfield frames

Table 2. Journal of observations of NGC 2425

UT Date Feb 1995	Filter	Exp. [sec]	Airmass	Seeing [arcsec]
21.092	I	5	1.031	1.70
21.094	I	15	1.031	1.47
21.098	I	100	1.031	1.56
21.101	V	15	1.032	1.70
21.102	V	100	1.032	1.63
21.104	V	300	1.032	1.51
21.110	B	30	1.034	1.64
21.111	B	150	1.035	1.51
21.114	B	500	1.037	1.64

were obtained in each filter. The average seeing was $1\farcs60$ and $2\farcs07$ on the first and second night, respectively. We observed 49 standard stars from the three fields (SA 98, Ru 149, PG 1323-086) listed by Landolt (1992), and 27 stars from two fields (SA 98, Ru 149) during the two subsequent nights. These standards were observed over airmasses from 1.07 to 1.76. The following relations between the instrumental (lower case letters) and the standard colours and magnitudes were adopted:

$$v = 2.561 + V - 0.019 \times (B - V) + 0.15 \times X \qquad (1)$$

$$b - v = 0.214 + 0.931 \times (B - V) + 0.12 \times X \qquad (2)$$

$$v - i = -0.668 + 1.019 \times (V - I) + 0.09 \times X \qquad (3)$$

where X is an airmass. The instrumental photometry was extracted with the DAOPHOT/ALLSTAR V2.0 (Stetson 1987) package. Aperture photometry of standards was obtained with an aperture radius of $8\farcs34$ arcsec (12 pixels). For stars from the cluster area we obtained profile photometry. Appropriate aperture corrections were derived preceding the transformation of instrumental photometry to the standard system.

We applied the following procedure to a set of images obtained for a given cluster. First, objects with unusually large errors of photometry, i.e. with large values of CHI and SHARP parameters, returned by DAOPHOT, were rejected. Also very bright, overexposed stars were removed from further analysis. In practice, the percentage of rejected stars ranged for a given frame from 5 to 15 percent. Second, the coordinates of all objects were transformed to a common pixel grid defined by the reference image (always the longest exposure in the V filter). We than corrected the photometry for the zero-point offset in each filter and created a master list of all objects. The instrumental magnitudes were calculated as weighted averages of magnitudes measured on individual frames.

3 NGC 2425

The open cluster NGC 2425 (C 0736-147) lacks any published study. We observed it on 1995 Feb 20/21. Details of the observations are presented in Table 2.

The cluster centre was found by calculating the density centre for stars inside a circle of radius of 150 pixels, using an iterative procedure similar to that described by Mateo & Hodge (1986). In Fig. 1 we show the density profile for all stars brighter than $V = 21.9$. The average stellar density was calculated in successive 27.8 arcsec (40 pixels) wide annuli around the cluster centre. The resulting density profile is rather noisy due to small number statistics. The smooth solid line represents a fit by the King (1962) profile:

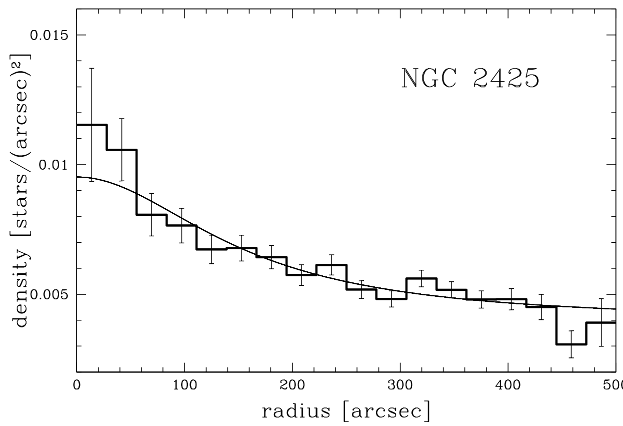

Figure 1. Surface density distribution of stars with $V < 21.9$ from NGC 2425 field. The King (1962) profile is fit to the data and presented as the smooth solid line.

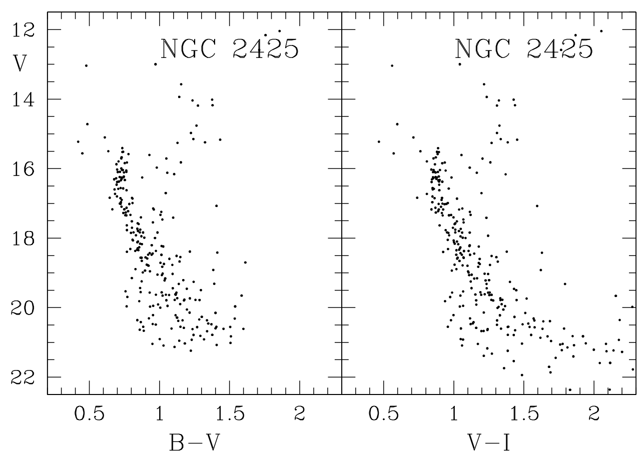

Figure 2. CMDs for the stars located within radius $r < 0.7\ r_c \approx 108''$ from the centre of NGC 2425

$$f(r) = \frac{f_0}{1 + (r/r_c)^2} + f_b \qquad (4)$$

where f_0 is the central density, r_c is the radius of the cluster core and f_b is the background density. For NGC 2425 we found as follows: $f_0 = 0.0056 \pm 0.0008$ stars per arcsec^2, $r_c = 154 \pm 41$ arcsec and $f_b = 0.0039 \pm 0.0004$ stars/arcsec^2. We estimate that the cluster contains about 850 stars with $V < 21.9$.

Colour-magnitude diagrams for the field of NGC 2425 are shown in two panels of Fig. 2. We plot only the innermost stars to get some structures, in particular the main sequence and red clump area. We can conclude that the morphology of CMDs for NGC 2425 is typical of intermediate-age open clusters. We note the presence of the red giant branch clump at $V \approx 14.1$, $B - V \approx 1.37$ and $V - I \approx 1.31$. One can also distinguish the main sequence turn-off point at $V \approx 16.5$,

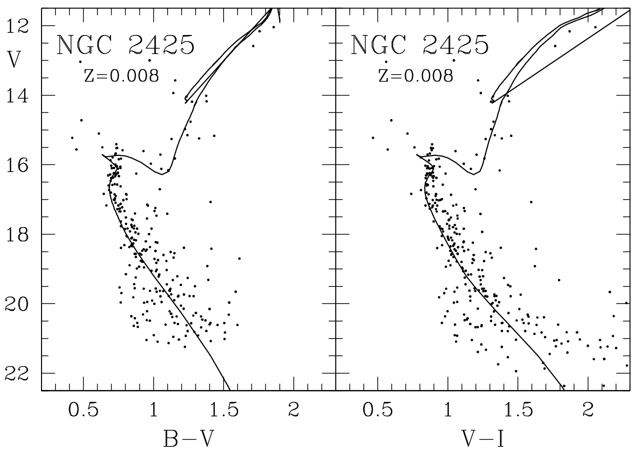

Figure 3. Left panel: $V/B-V$ diagram for the cluster NGC 2425, as compared to Girardi et al. (2000) isochrone of age 2.5×10^9 yr and metallicity $Z = 0.008$ (solid line). The fit was obtained by adopting a distance modulus of $(m-M)_V = 13.5$ and reddening of $E(B-V) = 0.29$. Right panel: field-star corrected $V/V-I$ diagram for NGC 2425 cluster, as compared to Girardi et al. (2000) isochrone of age 2.5×10^9 yr for the metallicity $Z = 0.008$ (solid line). The fit was obtained by adopting a distance modulus of $(m-M)_V = 13.5$ and reddening of $E(V-I) = 0.34$.

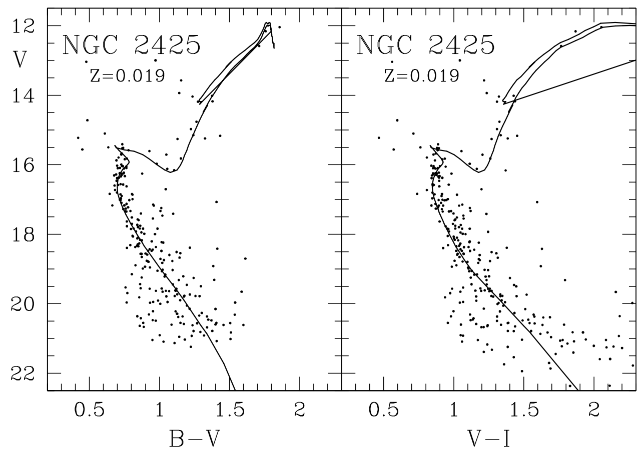

Figure 4. The same as Fig. 3, but for $Z = 0.019$. The fit in the left panel was obtained by adopting a distance modulus of $(m-M)_V = 13.3$ and reddening of $E(B-V) = 0.20$, whereas the fit in the right panel by adopting $(m-M)_V = 13.3$ and $E(V-I) = 0.26$.

$B-V \approx 0.68$ and $V-I \approx 0.84$. We suspect that there are candidates for blue stragglers among stars above the turn-off.

Using theoretical isochrones published by Girardi et al. (2000), we are able to estimate the basic parameters of the cluster. We fit isochrones with two different chemical compositions: $(Z, Y) = (0.008, 0.25)$ and $(0.019, 0.273)$. In Fig. 3 we show CMDs with superimposed isochrones of age of 2.5 Gyr and lower metal content, $Z = 0.008$. The shape of the main sequence for $16 < V < 20$ is well reproduced, while the blue and red hooks are not clearly seen. Comparing other isochrones to the data we estimated the uncertainty of the age as 0.5 Gyr. We derived, by shifting the isochrones, the apparent distance modulus of $(m-M)_V = 13.5$, the reddenings of $E(B-V) = 0.29$ and $E(V-I) = 0.34$. These values are lower than the upper limits of reddening $E(B-V) = 0.47$ and $E(V-I) = 0.60$ for $(l, b) = (231.5, +3.3)$ extracted from the maps of Schlegel, Finkbeiner & Davis (1998). We assume the error of the distance modulus as 0.1 mag, and the error of the reddening $E(B-V)$ as 0.05 mag.

Fig. 4 presents the CMDs of NGC 2425 with superimposed isochrones of the same age, as in Fig. 3, but with solar metal abundance, $Z = 0.019$. The fit is worse just above the turn-off point while the RGB branch is reproduced quite well. In this case we established: $(m-M)_V = 13.3 \pm 0.1$, $E(B-V) = 0.20 \pm 0.05$, $E(V-I) = 0.26 \pm 0.05$. Adopting $R_V = 3.2$ and taking into account the results for both metallicites we estimated the minimum value of the heliocentric distance of the cluster as $d_{min} = 2.9$ kpc and the maximum value $d_{max} = 3.8$ kpc.

4 HAFFNER 10 AND CZERNIK 29

The clusters Haffner 10 (OCl 594, C 0726-152) and Czernik 29 (OCl 595, C 0726-153) were identified by Haffner (1957) and Czernik (1966), respectively. Later Fitzgerald & Moffat (1980) studied the clusters based on photographic UBV plates. However, due to rather low photometric limits ($B = 18$, $V = 15.1$) they underestimated the number of stars in the clusters (68 ± 12 in Haffner 10 and 56 ± 11 in Czernik 29 based on B filter data) and the age of Haffner 10 (0.2 Gyr). We observed these clusters on 1995 Feb 20/21 and 21/22. The list of used CCD frames is given in Table 3. The angular separation between the clusters is only $3\overset{\prime}{.}8$ and both of them were embraced within each frame.

Table 3. Journal of observations of Haffner 10

UT Date Feb 1995	Filter	Exp. [sec]	Airmass	Seeing [arcsec]
21.127	I	10	1.054	1.37
21.129	I	60	1.057	1.81
21.130	I	180	1.059	1.50
21.135	V	20	1.067	1.43
21.136	V	100	1.069	1.63
21.138	V	360	1.073	1.63
21.144	B	40	1.084	1.69
21.146	B	150	1.089	1.63
21.149	B	500	1.093	1.72
22.056	V	20	1.046	2.36
22.058	B	40	1.043	2.30
22.060	I	10	1.041	1.86
22.062	I	300	1.040	2.03
22.067	V	600	1.036	2.00
22.077	B	900	1.031	1.88

As for previous cluster, for Haffner 10 and Czernik 29 we present the density histograms (Fig. 5). The histograms include stars with $V < 21.7$. We determined the centres of the clusters and calculated the average stellar density in successive 27.8 arcsec (40 pixels) annuli around the centre, excluding regions within the $1\overset{\prime}{.}9$ area around the neighbouring cluster. This radius is equal to half the angular distance between the clusters, which are of comparable size (from Fitzgerald & Moffat 1980).

For Haffner 10 the best fit of King's profile results in the following coefficients: the central density $f_0 = 0.0123 \pm$

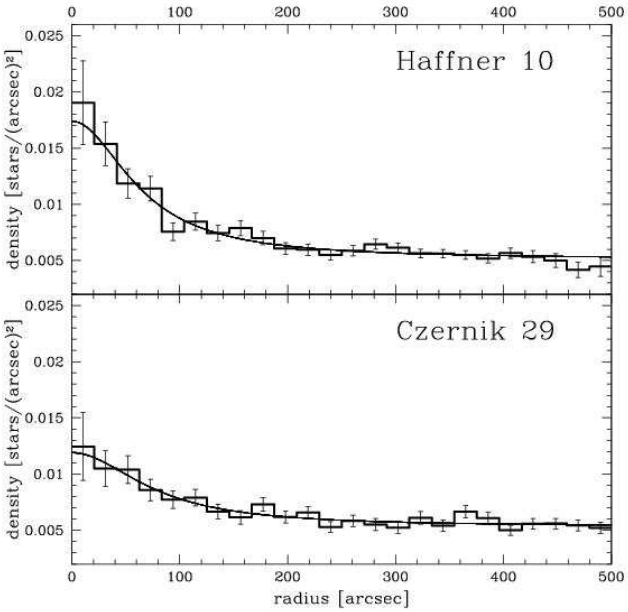

Figure 5. Surface density distributions of stars with $V < 21.7$ from the field of Haffner 10 and Czernik 29

0.0020 stars/arcsec^2, the radius of the cluster core $r_c = 65 \pm 11$ arcsec and the background density $f_b = 0.0051 \pm 0.0002$ stars/arcsec^2. We established the number of cluster stars with magnitude $V < 21.7$ to be approximately 600 objects. This was determined by adopting the above value of f_b. For Czernik 29 we found: the central density $f_0 = 0.0066 \pm 0.0013$ stars/arcsec^2, the radius of the cluster core $r_c = 78 \pm 17$ arcsec and the background density $f_b = 0.0053 \pm 0.0002$ stars/arcsec^2. The number of cluster stars with magnitude $V < 21.7$ is approximately 420 objects.

In Fig. 6 we present $V/B-V$ and $V/V-I$ colour-magnitude diagrams for Haffner 10. The morphology of CMDs is typical for intermediate-age open clusters. Interestingly, the red clump is represented by a tilted branch. Its width reaches 0.20 in the $B-V$ and 0.22 in the $V-I$. The branch is elongated in the direction parallel to the standard reddening vector. It means that there is significant differencial absorption in the cluster direction. The blue turn-off point is located at $V \approx 17.3$, $B-V \approx 0.92$ and $V-I \approx 1.18$, while the blue end of the red clump is located at $V \approx 14.8$, $B-V \approx 1.41$ and $V-I \approx 1.58$.

Using a set of theoretical isochrones published by Girardi et al. 2000 we estimated some cluster parameters, in particular the age and the heliocentric distance. As in the case of NGC 2425, we adopted isochrones for two different metallicites. Figures 7 and 8 show CMDs with superimposed isochrones of 2.5 Gyr for metallicity $Z = 0.008$ and of 2.0 Gyr for $Z = 0.019$, respectively. The fit for lower metal content seems to be more precise. However we note that it is difficult to establish the location of the blue and red hooks. Trying to improve the fit and comparing other isochrones we estimated the error of the age as 0.5 Gyr. By shifting the isochrones for both metallicities, we obtained the value of the apparent distance modulus $(m-M)_V$ between 14.3 and 14.7, the reddenings $0.41 < E(B-V) < 0.64$ and $0.58 < E(V-I) < 0.78$. This is in agreement with the upper value of the interstellar reddening, $E(B-V) = 0.89$

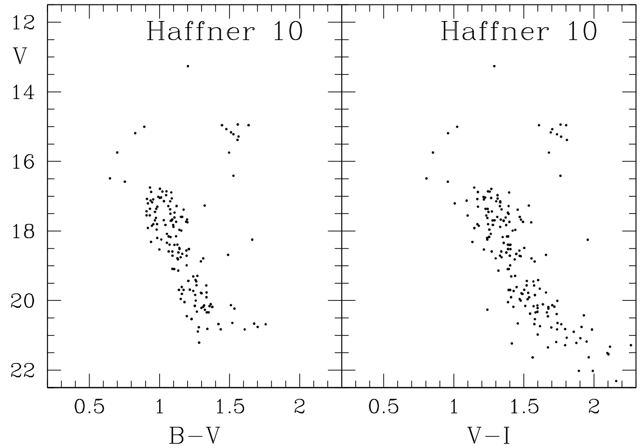

Figure 6. CMDs for the stars located within radius $r < 1.2\ r_c \approx 78''$ from the centre of Haffner 10

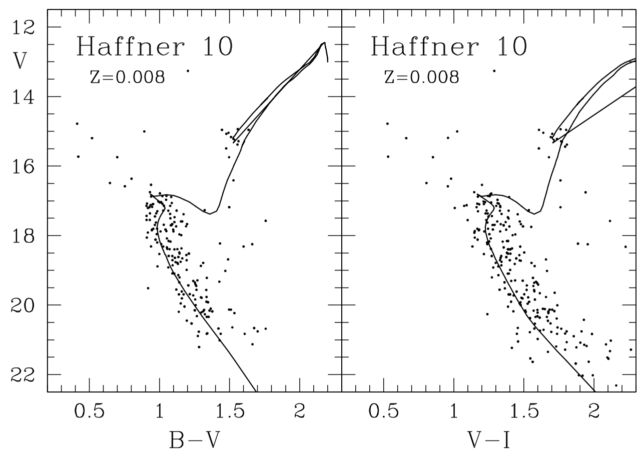

Figure 7. Left panel: $V/B-V$ diagram for the cluster Haffner 10, as compared to Girardi et al. (2000) isochrone of age 2.5×10^9 yr for the metallicity $Z = 0.008$ (solid line). The fit was obtained by adopting a distance modulus of $(m-M)_V = 14.6$ and reddening of $E(B-V) = 0.59$. Right panel: field-star corrected $V/V-I$ diagram for the Haffner 10 cluster, as compared to Girardi et al. (2000) isochrone of age 2.5×10^9 yr for the metallicity $Z = 0.008$ (solid line). The fit was obtained by adopting a distance modulus of $(m-M)_V = 14.6$ and reddening of $E(V-I) = 0.73$.

and $E(V-I) = 1.14$, for $(l,b) = (230.8, +1.0)$ derived from maps presented by Schlegel, Finkbeiner & Davis (1998). We estimated that the heliocentric distance d to Haffner 10 is in the range between 3.1 and 4.3 kpc.

Figure 9 shows $V/B-V$ and $V/V-I$ colour-magnitude diagrams for Czernik 29. The cluster lacks the red giant clump, which makes estimation of its age and distance difficult. The main sequence has brighter stars than the main sequence of Haffner 10, therefore Czernik 29 is either younger or/and has a lower distance than Haffner 10.

5 SUMMARY

We have presented BVI photometry for three poorly studied open clusters from the southern hemisphere. For each cluster we calculated surface density profile and established the probable number of cluster members. The analysis of

Table 4. Observed and determined parameters of analysed open clusters

Name	r_c [arcsec]	N	$(m-M)_V$ [mag]	$E(B-V)$ [mag]	d [kpc]	Age [Gyr]
NGC 2425	155	850	13.2-13.6	0.15-0.34	2.9-3.8	2.5 ± 0.5
Haffner 10	65	600	14.3-14.7	0.41-0.64	3.1-4.3	2.5 ± 0.5
Czernik 29	78	420	-	-	-	-

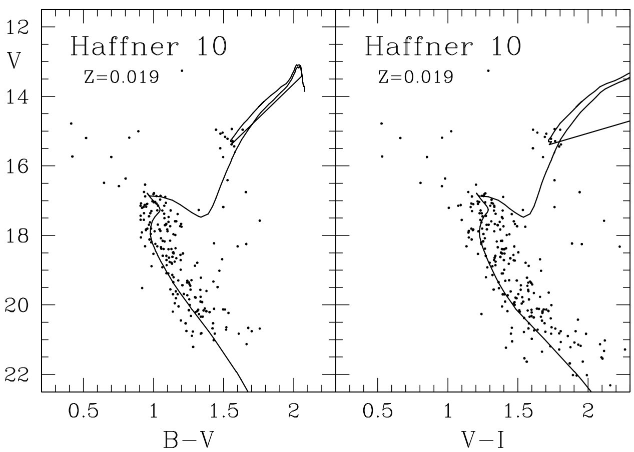

Figure 8. CMDs for the cluster Haffner 10 with superimposed isochrones of age 2.8×10^9 yr for the metallicity $Z = 0.019$. The fit in the left panel was obtained by adopting a distance modulus of $(m-M)_V = 14.4$ and reddening of $E(B-V) = 0.46$, whereas the fit in the right panel by adopting $(m-M)_V = 14.4$ and $E(V-I) = 0.63$.

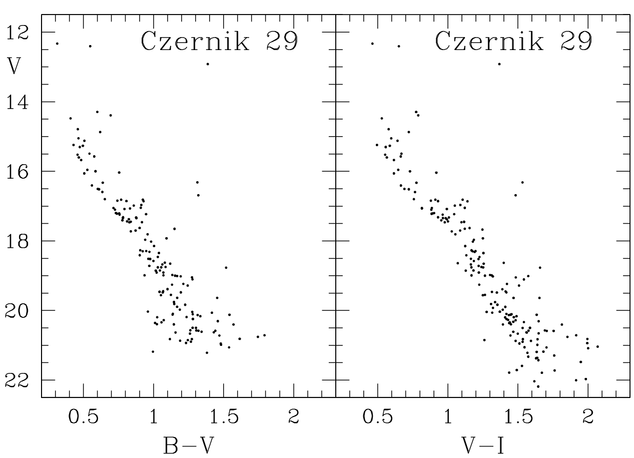

Figure 9. CMDs for the stars located within radius $r < 1.2\, r_c \approx 94''$ from the centre of Czernik 29

the derived colour-magnitude diagrams allowed us to estimate basic parameters like the age and distance. The results are summarized in Table 4. We found that the clusters NGC 2425 and Haffner 10, are intermediate-age open clusters. Probably due to the relatively large number of star members, the clusters still constitute physical systems.

We notice that the age as well as the heliocentric distance estimations of the two clusters are very similar, though the extinctions are quite different. Interestingly, the angular separation between the clusters is only $2\overset{\prime}{.}4$, which gives an approximate linear seperation of 150 pc, assuming an average distance of 3.65 kpc. This is about 50 and 100 times larger than the cluster core radius of NGC 2425 and Haffner 10, respectively. We should note that the seperation is larger than for other double systems of clusters presented in the literature (Subramaniam et al. 1995, Pietrzyński & Udalski 2000). However, there is a possibility that the two clusters constituted a pair of open clusters in the past.

Based on the comparison of the CMDs with the theoretical isochrones we were not able to firmly establish the metallicity of either of the clusters. We may only suggest that the metal abundance is comparable for both clusters, which may indicate a common origin. A spectroscopic determination of the metallicity and radial velocities would help to verify this hypothesis.

ACKNOWLEDGMENTS

We would like to thank Greg Stachowski for remarks on the draft version of this paper. PP was supported by the grant **1 P03D 024 26** from the State Committee for Scientific Research, Poland.

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